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Chemi-resistive sensors based on platinum nanoparticle arrays

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Abstract

The design and implementation of a chemi-resistor sensor utilizing platinum nanoparticles and a poly(2-hydroxyethyl methacrylate) (PHEMA) polymer layer is presented. The sensor was fabricated utilizing a magnetron sputtering system for the gas phase synthesis of metallic nanoparticles and an ink-jet printer for the PHEMA polymer delivery. The platinum nanoparticles have been deposited on oxidized silicon substrates which have been previously patterned with gold interdigitated electrodes. Following the nanoparticles deposition a PHEMA polymer layer has been delivered on top, using the ink-jet printing technique. By controlling the density of the metal nanoparticle film, sensors of different sensitivity can be fabricated.

Keywords: gas sensor; humidity sensor; nanoparticle; PHEMA

1. Introduction

Metallic nanoparticles of different size and of varying molecular capping have been widely investigated over the past years as potential chemical sensing devices. Their increased sensing performance and unique properties makes them one of the most promising transducer materials in the field of biological and chemical sensing [1]. Previous work has investigated the application of hygroscopic PHEMA to an array of gold nanoparticles, resulting in a measured response to small quantities of water and ethanol vapour [2]. The nanoparticles were applied to the substrate in the form of colloid by ink-jet printing, followed by the deposition of the polymer in the same way. The evaporative nature of the colloid resulted in the nanoparticles being transported to the droplet edge, forming a "ring" of higher density. The current work employs the same application of PHEMA but aims to provide a more

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Nomenclature

PHEMA	poly(2-hydroxyethyl methacrylate)
NPs	nanoparticles

uniform nanoparticle distribution, and so greater sensitivity. The nanoparticles are formed in vacuum, based on sputtering and condensation of atoms from a metallic target to form clusters of controlled size that are uniformly deposited on the substrate [3].

2. Experimental

Gold interdigitated electrodes with electrode gaps of 5 μm were applied by optical lithography and e-gun evaporation to silicon substrates with 1 μm thermal oxide layer. Platinum nanoparticles were deposited through a second lithographic mask at room temperature using a modified magnetron sputtering apparatus whereby the gas phase material is condensed into aggregate particles in a preliminary chamber before arriving at the substrate [3]. The density of nanoparticles was controlled by adjusting the deposition time between 10 minutes and 16 minutes. 1000 drops of ethyl-lactate solution with 0.5% PHEMA concentration were deposited onto the devices using a 5 Hz printing frequency, resulting in a functional device such as that shown in figure 1.

The devices were characterised electrically using an HP4041B picoampere meter. Sensitivity to analyte vapors was measured by situating the devices in a small volume chamber (approximately 4 mm^2) where temperature and humidity could be carefully controlled.

3. Results

The resistance of devices with platinum nanoparticle deposition times of 10 minutes and 16 minutes were measured as a function of temperature, shown in figure 2. Clearly the resistance decreases as the temperature is increased; an indication that the nanoparticle film is discontinuous [4]. The gas sensing response of the device with 10 minute platinum deposition time to water and ethanol is presented in figures 3. Sensitivity is improved by an order of magnitude when compared with values achieved in the

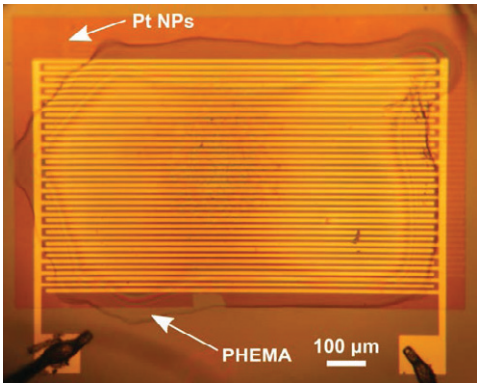

Figure 1: Optical microscope photograph depicting the finished device, showing the nanoparticle rectangular array and PHEMA layer

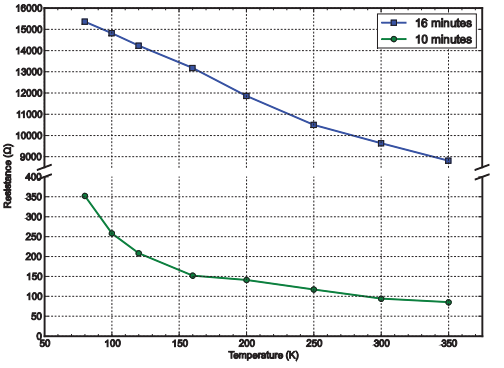

Figure 2: Resistance as a function of temperature for devices with platinum nanoparticle deposition times of 10 minutes and 16 minutes

previous announcement [2], relating to either the lower density or larger area of nanoparticles that contribute to the conduction path. A strong resistance change is detected at the lowest concentration of 2000 ppm for both analyte vapors.

Figure 4 shows the resistance of devices with 16 minute platinum deposition during exposure to water and ethanol vapour respectively for 5 µm electrode gaps. Evidently the response is more moderate; this is more clearly shown in figure 5. Relating to figure 2 it may be observed that the sample with higher initial resistance provides a greater sensitivity to analyte gasses. The lateral expansion of the PHEMA layer likely increases the inter-particle distance. For electrical transport mechanisms appropriate to nanoparticle films such as this, the exponential relationship of distance with resistance ensures that greater inter-particle distance results in greater sensitivity to changes in this distance [1, 5].

Electrode gap dimensions provide some degree of control to device sensitivity but the nanoparticle density, an easily controllable parameter, is prominent in adjusting the sensitivity of devices.

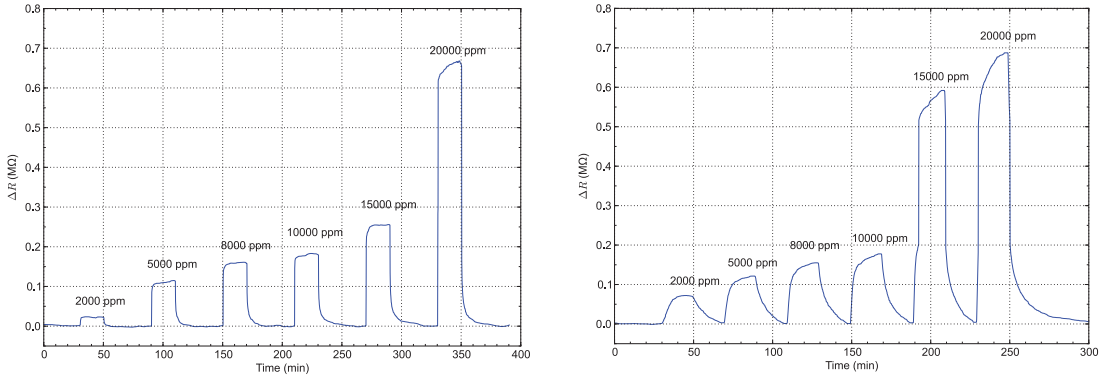

Figure 3: Transient sensor response of device using 10 minute deposition of platinum nanoparticles in water vapour (left) and ethanol vapour (right).

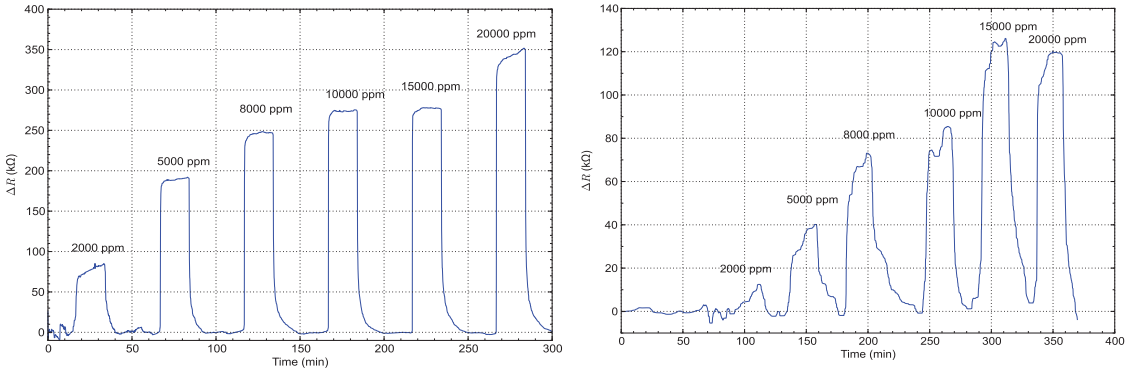

Figure 4: Transient sensor response of device using 16 minute deposition of platinum nanoparticles in water vapour (left) and ethanol vapour (right).

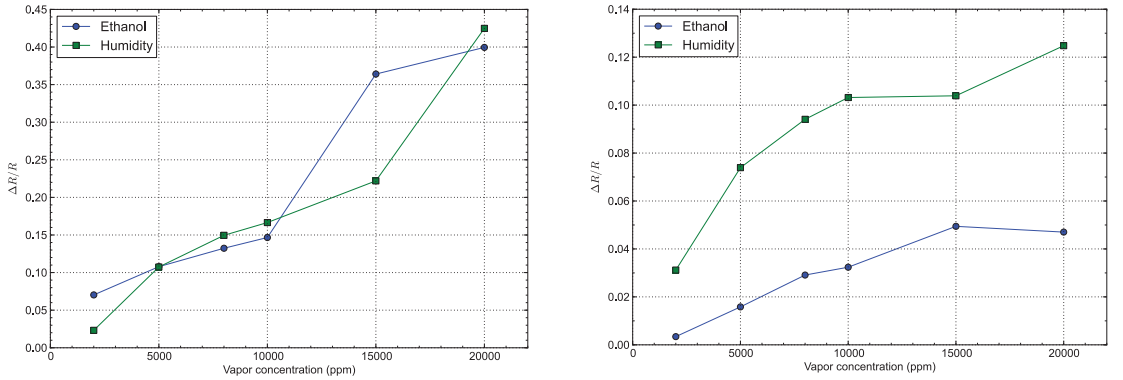

Figure 5: Relative resistance response for humidity and ethanol vapor concentrations from 2000 ppm up to 20000 ppm for 10 minutes deposition (left) and 16 minutes deposition (right).

4. Conclusions

The resistance of platinum nanoparticle arrays with a PHEMA functional layer has been shown to change in the presence of small quantities of water and ethanol vapour. Expansion of the PHEMA layer increases the inter-particle distance, resulting in an increase in resistance. Lower nanoparticle density provides greater sensitivity.

Acknowledgements

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